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Detection Performance Degradation Due to Signal Uncertainties

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Detection of a known signal in white noise using a matched filter depends on the signal-to-noise ratio (signal energy to noise spectral density). As the uncertainties of signal characteristics, such as phase and amplitude, increase, the required SNR must be increased in order to maintain the same detection performance. However, in both cases of known and unknown signals, it is usually tacitly assumed that the signal covers the total bandwidth of the detector and the total integration time. But, in real ocean environments, it is difficult to know the exact signal arrival time and the exact bandwidth required to cover the wide range of Doppler shifts. As a result, the actual detector may utilize a wider bandwidth, and the integration time may extend beyond the signal duration. This paper addresses the problem where the signal duration L is less than or equal to the actual integration time T, and the signal bandwidth B is equal to or

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19. ABSTRACT (Cont'd.)

less than the actual bandwidth W of the detector. The performance loss is shown as a function of TW/BL as it varies over a range of 1 to 1000, for various combinations of probability of detection and probability of false alarms. (Work supported by NUSC special initiative program.)

DETECTION PERFORMANCE DEGRADATION DUE TO SIGNAL UNCERTAINTIES

BY

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The following 5 pages give the text of the oral presentation at the JASA meeting.

The succeeding 10 pages constitute the poster presentation. The particular 5 pages that were employed for the oral presentation are labeled with VG1, VG2, VG3, VG4, VG5, at the top center.

VU-GRAPH 1

This paper addresses the problem of performance evaluation of a signal detection scheme in the presence of uncertainties, such as the signal location in time and frequency, as well as the signal duration and bandwidth. More specifically, we present a cookbook procedure whereby mismatch or lack of knowledge can be incorporated in the analysis and yield an approximation to the degradation of performance.

VU-GRAPH 2

Here we define the problem. Namely, we are trying to detect an unknown deterministic signal s(t) which has a bandwidth B Hz centered at f_o Hz, and has a duration of L seconds. The time-frequency region that must be searched in order to detect this signal has bandwidth W Hz and observation time T seconds. The reason that the search bandwidth and observation time are larger than the signal bandwidth and duration is that, in the real ocean environment, for active as well as passive detection, it is difficult to know a priori the range of a target or its doppler shift. Due to this lack of knowledge, we need to cover a wider bandwidth and larger observation time, in order to guarantee capturing the signal.

Our objective is to obtain the detector performance characteristics, which show the required input signal to noise ratio vs the degrees of freedom in the search region of size T by W, for specified probability of detection and probability of false alarm.

VU-GRAPH 3

Here we show the receiver processing of interest, namely the usual bandpass energy detector. The bandpass filter has the bandwidth W Hz, while the integration time is T seconds. The integrator can be continuous or discrete in time. The processor output y is compared with a threshold for a decision on signal presence or absence in the TW region under investigation.

The approximate analysis of performance procedure consists of two parts. In the first part, the equivalent degrees of freedom D of decision variable y is determined. Then, the detection probability for a given number of degrees of freedom is evaluated.

VU-GRAPH 4

This plot shows the equivalent degrees of freedom D as a function of the TW product, for the particular case of a flat noise spectrum and a rectangular integrator. The parameter K is the number of samples employed in the discrete integrator over its effective time duration T. More generally, we have considered colored noise spectra, tapered filters, and weighted integrators, and the degrees of freedom have been evaluated for these various combinations. In fact, this is the essence of the cookbook procedure we are presenting, namely a different plot for each combination of noise spectrum, filter, and integrator. This procedure allows the working engineer to quickly and accurately assess the losses to be expected in any suboptimum processing candidate scheme.

VU-GRAPH 5

This plot shows the detection performance in terms of the required input signal to noise ratio vs. the equivalent degrees of freedom D determined in the previous plot. Here, the particular detection probability is .5, while the false alarm probability takes on several representative values. It is seen that the required input signal to noise ratio increases with increasing D, the degrees of freedom. This is as expected, because larger degrees of freedom are the result of having to consider a larger search region.

In conclusion, this approach is applicable to:

(a) Lowpass as well as bandpass energy detectors,

(b) Continuous and discrete integrators,

(c) Arbitrary noise spectra and filter characteristics,

(d) Low as well as high TW products.

Furthermore, slow fading can and has been incorporated in the analysis, but is not presented here, due to lack of time.

VG1

DETECTION PERFORMANCE DEGRADATION DUE TO SIGNAL UNCERTAINTIES

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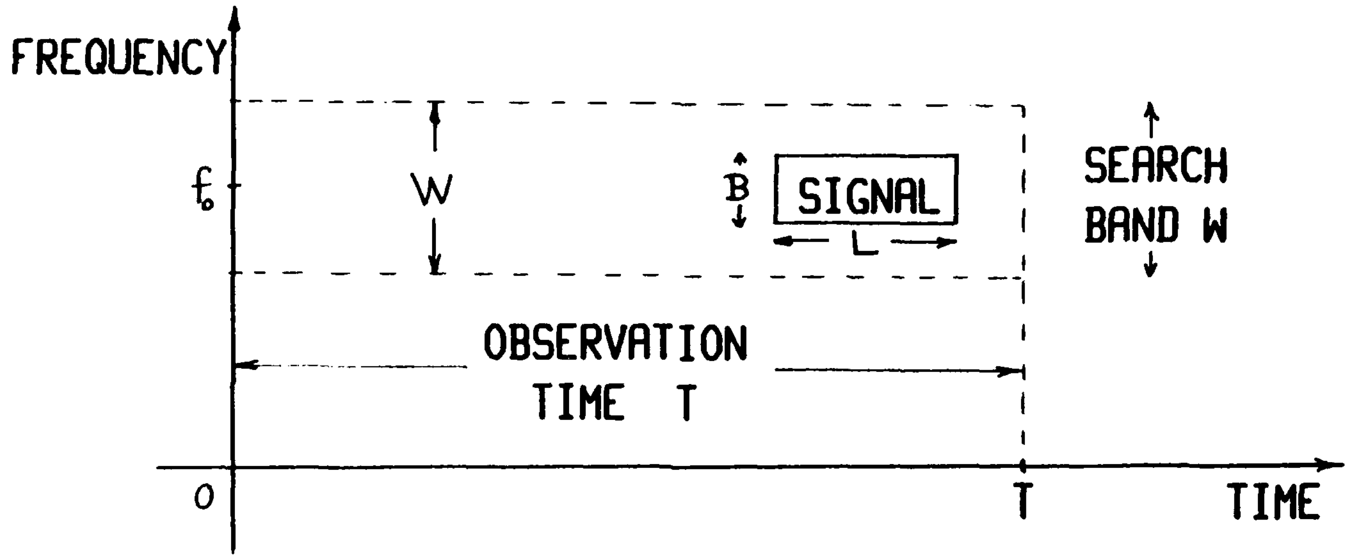
SHERATON-WAIKIKI HOTEL
HONOLULU, HAWAII

15 NOVEMBER 1988

TIME-FREQUENCY REGIONS



UNKNOWN DETERMINISTIC SIGNAL s(t) LIES COMPLETELY WITHIN SEARCH REGION T x W. THAT IS, $L \leq T$, $B \leq W$.

SIGNAL SOURCE (IF PRESENT) IS AT UNKNOWN RANGE AND DOPPLER.

VG2

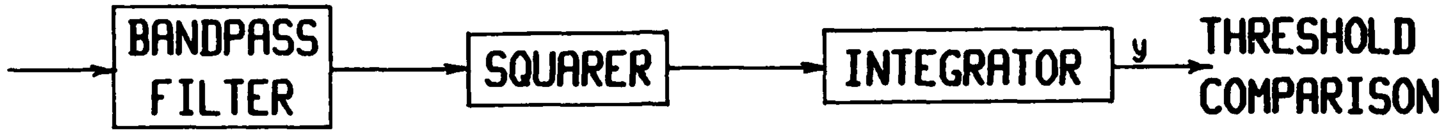
SIGNAL AND NOISE STATISTICS

DETAILED DETERMINISTIC SIGNAL WAVESHAPE UNKNOWN.
SIGNAL LOCATION IN TIME AND FREQUENCY UNKNOWN.
SIGNAL DURATION L AND BANDWIDTH B UNKNOWN.
BL SIGNAL PRODUCT ARBITRARY.

ADDITIVE NOISE $n(t)$ IS ZERO-MEAN GAUSSIAN, AND
IS STATIONARY OVER TOTAL OBSERVATION TIME T.
NOISE SPECTRUM CAN BE COLORED, BUT
SPECTRAL LEVEL AND SHAPE MUST BE KNOWN.

RECEIVER PROCESSING

VG3



BANDPASS ENERGY DETECTOR

FILTER IS CENTERED AT f_o HZ, HAS BANDWIDTH W HZ, AND CAN HAVE ANY SHAPE.

INTEGRATOR DURATION IS T SECONDS, AND CAN INCLUDE BOX-CAR OR EXPONENTIAL WEIGHTING IN TIME. INTEGRATOR CAN BE CONTINUOUS OR DISCRETE. SAMPLING TIMES ARE ARBITRARY.

PROCESSOR OUTPUT y IS COMPARED WITH A THRESHOLD FOR A DECISION ON SIGNAL PRESENCE IN T x W REGION.

PROBLEM DEFINITION

IMPORTANT PARAMETERS:

- T = OBSERVATION TIME
- W = SEARCH BAND
- E = RECEIVED SIGNAL ENERGY
- N_o = SINGLE-SIDED RECEIVED NOISE SPECTRAL LEVEL (FOR FLAT SPECTRUM)

WANT PROB(y > THRESHOLD | SIGNAL PRESENT)

CAN THEN DETERMINE P_F AND P_D

TW PRODUCT IS ARBITRARY; NO ASSUMPTION ON LARGE TW.

ANALYTIC APPROACH

APPROXIMATE DECISION VARIABLE (PROCESSOR OUTPUT) y BY

1) CHI-SQUARED VARIATE v FOR NOISE-ONLY
2) NON-CENTRAL CHI-SQUARED VARIATE FOR SIGNAL+NOISE

DETERMINE EQUIVALENT NUMBER OF DEGREES OF FREEDOM D OF v BY EQUATING MEAN AND VARIANCE OF v TO THOSE OF y

PROB(v > THRESHOLD) = $Q_{D/2}(A, B)$, WHERE

$$A = \left(\frac{E}{N_0}\,\frac{D}{TW}\right)^{1/2}, \quad B = \text{NORMALIZED THRESHOLD}$$

$$Q_M(\alpha, \beta) = \int_{\beta}^{\infty} dx\, x \left(\frac{x}{\alpha}\right)^{M-1} I_{M-1}(\alpha x) \exp\left(-\frac{x^2+\alpha^2}{2}\right)$$

PROCEDURE

$$P_F = Q_{D/2}(0, B) \qquad (1)$$

$$P_D = Q_{D/2}(A, B), \quad A = \left(\frac{E}{N_0} \frac{D}{TW}\right)^{1/2} \qquad (2)$$

GIVEN NOISE SPECTRUM, FILTER, INTEGRATOR TYPE, AND TW, DETERMINE EQUIVALENT DEGREES OF FREEDOM D

GIVEN D AND SPECIFIED P_F, SOLVE (1) FOR B

GIVEN D, B, AND SPECIFIED P_D, SOLVE (2) FOR A AND E/N_0

PLOT E/N_0 VS TW, WITH P_F AND P_D AS PARAMETERS

SUMMARY AND CONCLUSIONS

BANDPASS AS WELL AS LOWPASS ENERGY DETECTORS

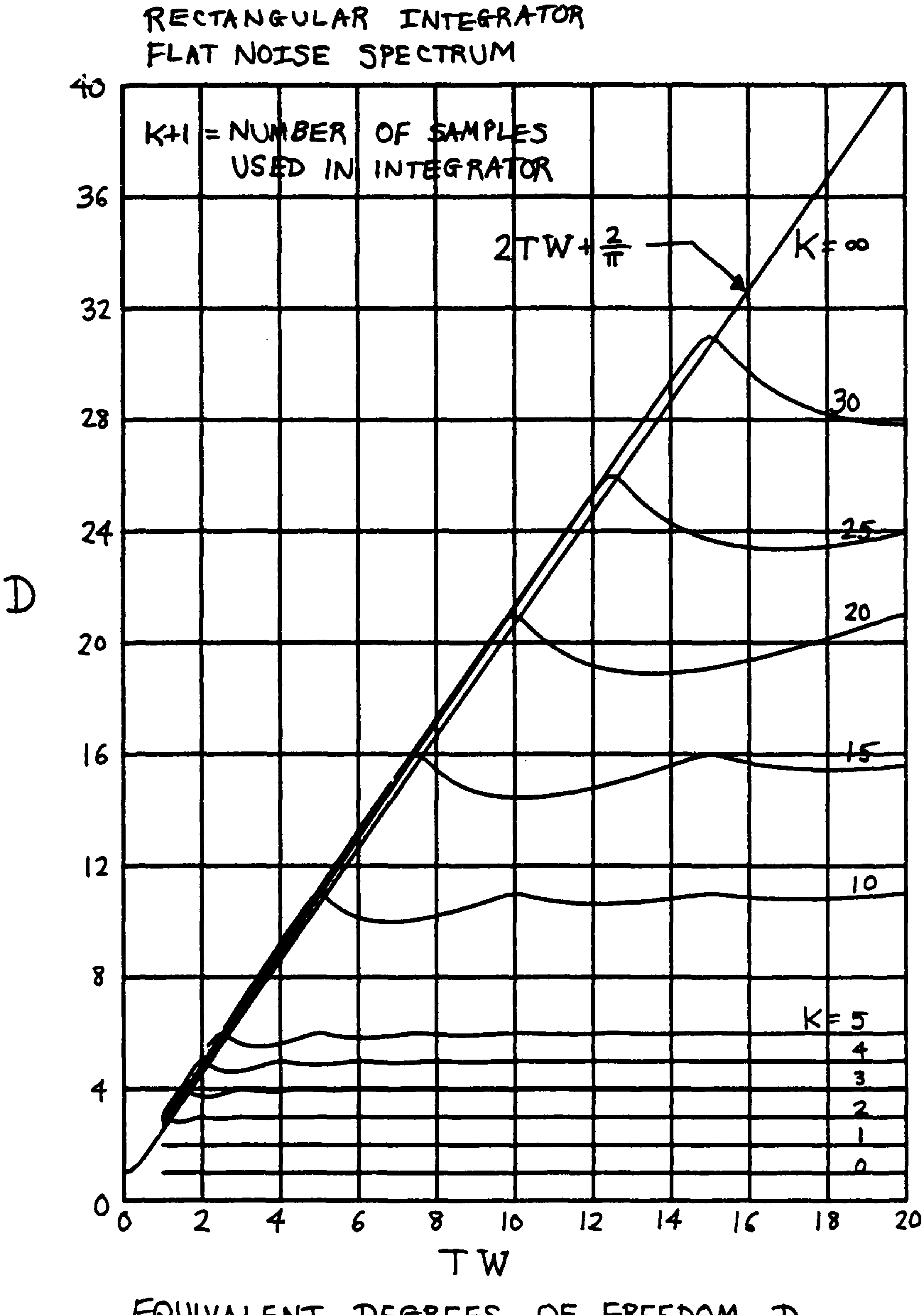
CONTINUOUS AND SAMPLED INTEGRATORS

ARBITRARY NOISE SPECTRUM AND FILTER CHARACTERISTICS

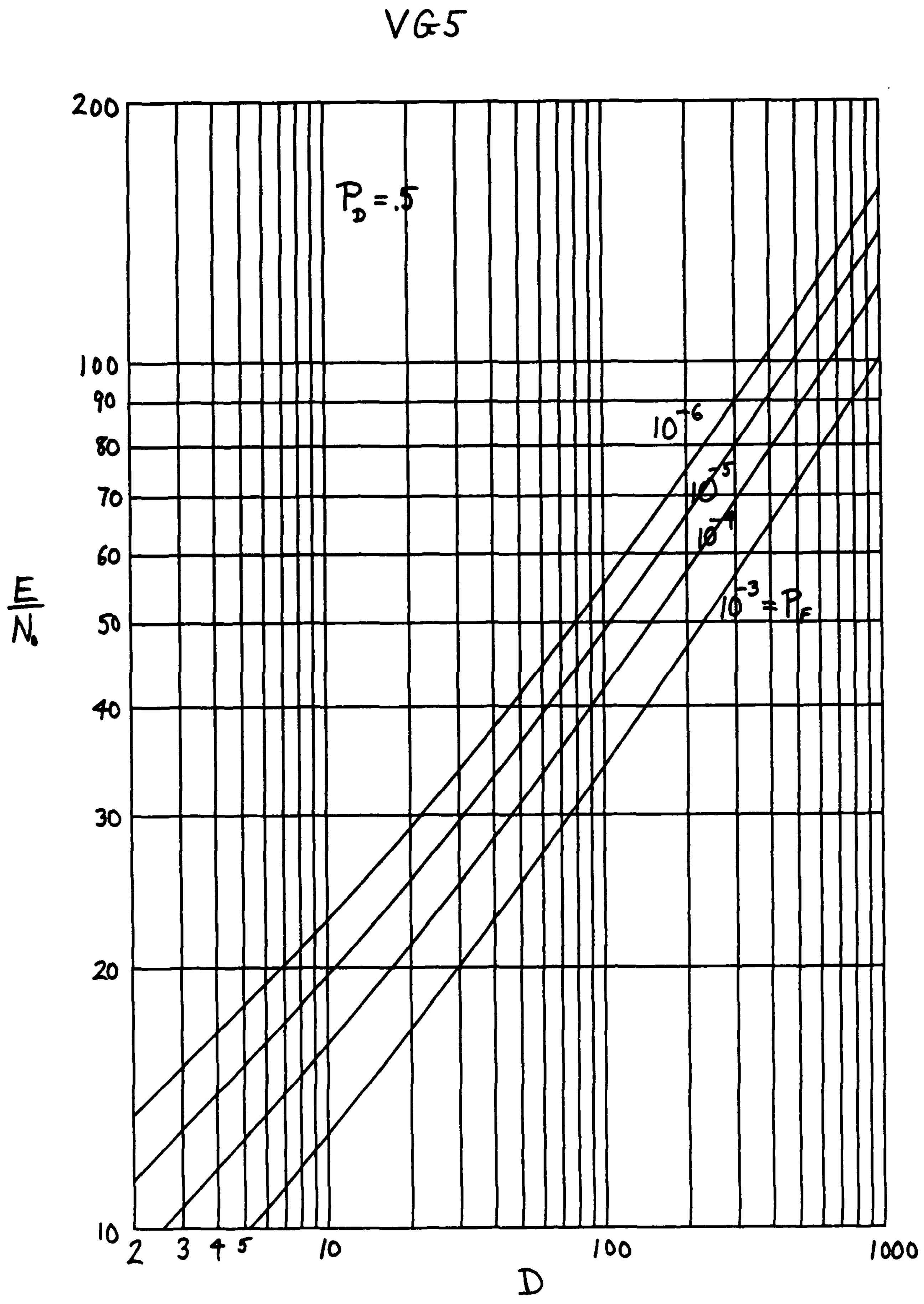
LOW TW PRODUCT AS WELL AS LARGE

SLOW SIGNAL FADING CAN BE INCORPORATED

VG4



EQUIVALENT DEGREES OF FREEDOM D
VERSUS SEARCH AREA TW



VG5
P_D = .5
200
100
90
80
70
60
50
40
30
20
10
E/N₀
2
3
4
5
10
100
1000
D
10^-6
10^-5
10^-4
10^-3 = P_F

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